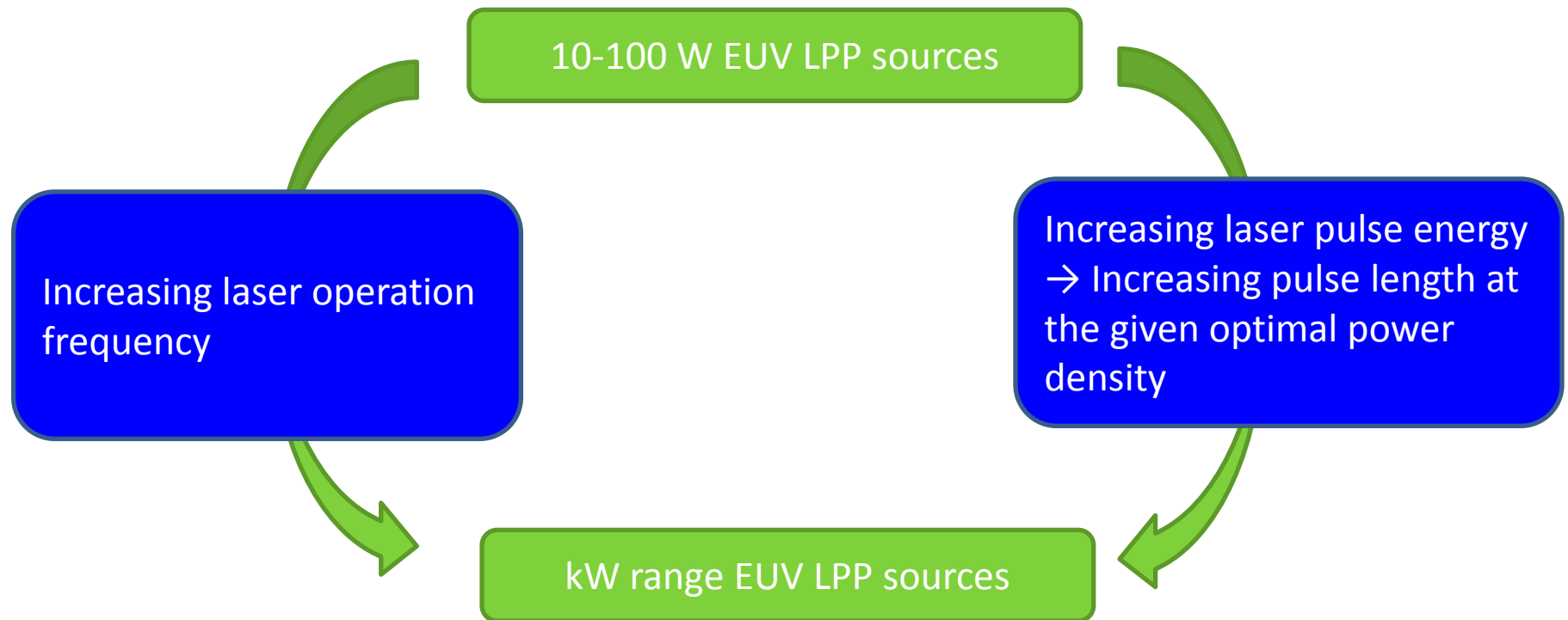


# Research review on plasma-based EUV sources at RnD-ISAN/EUV Labs

V.Krivtsun, D.Abramenko, V.Bushuev, A.Chekmarev,  
R.Gayazov, M.Spiridonov, O.Yakushev, G.Zukakishvili and  
K.Koshelev

ISAN, RnD-ISAN, EUV Labs  
Moscow, Troitsk

# Strategies for EUV source power scaling



# LPP : Target and laser pulse tailoring

Tasks: Find ways to increase power of EUV source

Optimization of :

CE vs type of target, laser pulse  
debris production vs target geometry  
and IR reflection

Lasers:

CO<sub>2</sub>

- 1) TEA ; pulse duration up to 4  $\mu$ sec
  - 2) EBP ; pulse duration up to 60  $\mu$ sec
- Simulation of long pulse duration regime**

Nd-YAG

- 1) Pulse duration 1 – 2 ns
- 2) Pulse duration – 20 - 100 ns

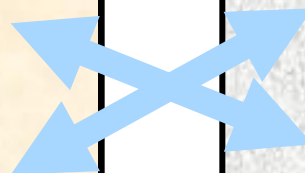
Targets :

Sn

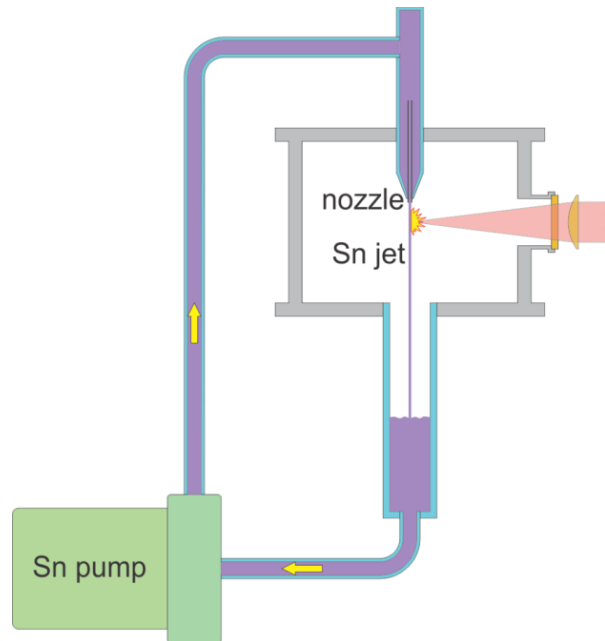
- 1) Solid Sn
- 2) Liquid jet

Gd, Tb

- 1) Foils
- 2) Solid



# Liquid tin jet targets :



Entirely closed system with rotary pump

Tin jet velocity 5 – 15 m/s

Jet profile determines by nozzle shape

Pump and jet characteristics:

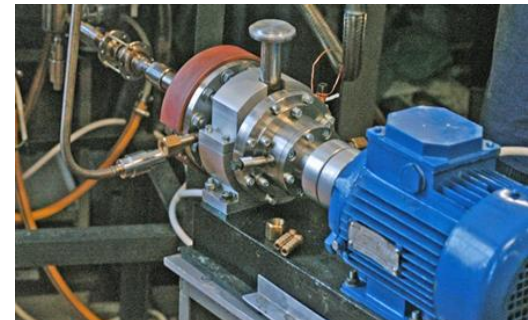
Rotation speed – **3000** rpm

Pressure – up to **8** bar

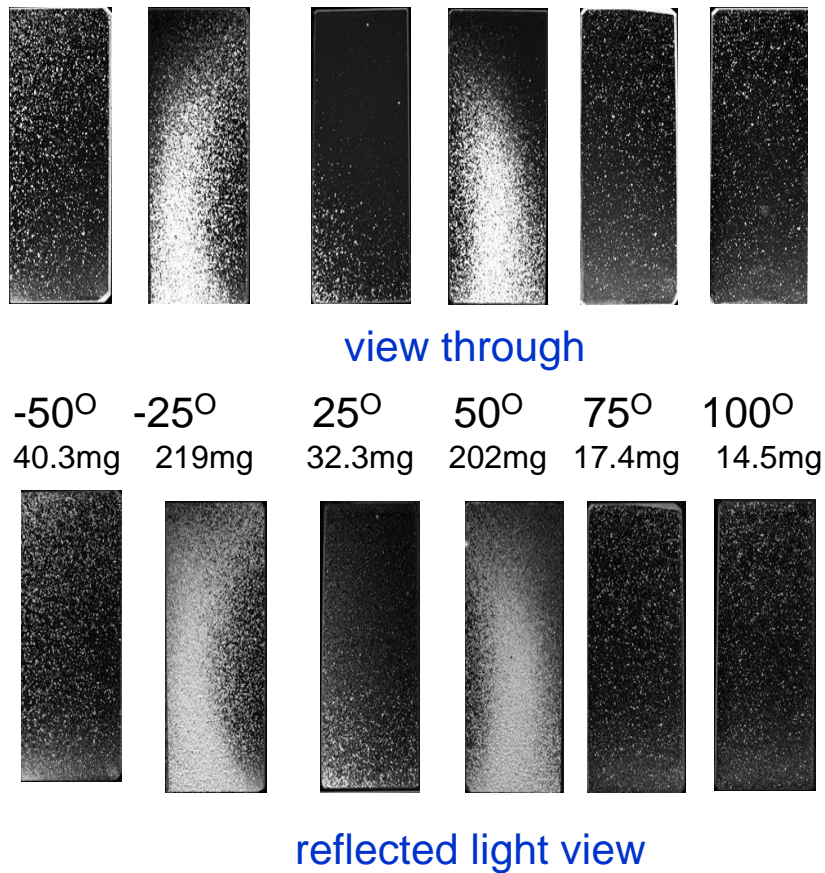
Production – **120** cm<sup>3</sup>/s

Speed of tin jet – up to **15** m/s

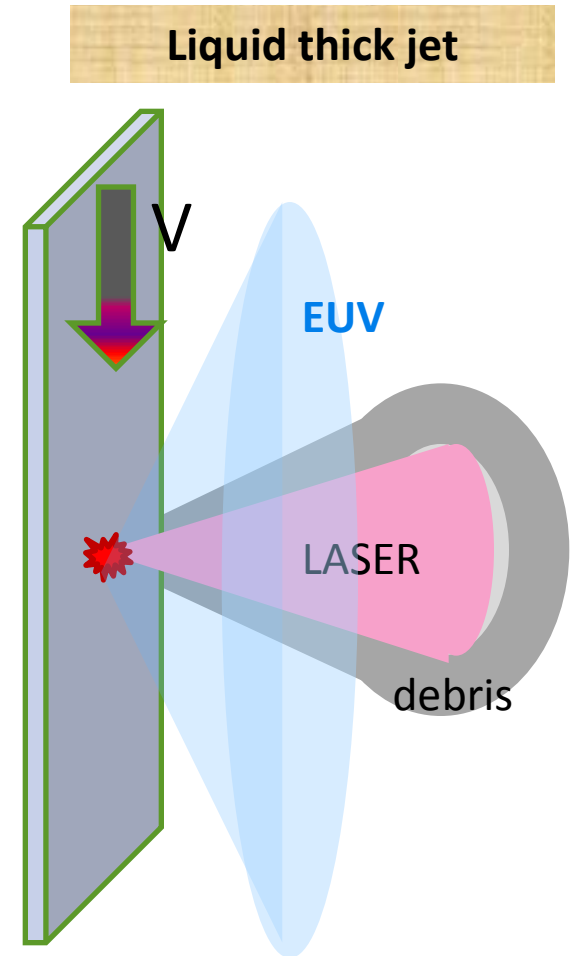
Max. temperature – **350** C



# Droplet type Sn debris angular distribution

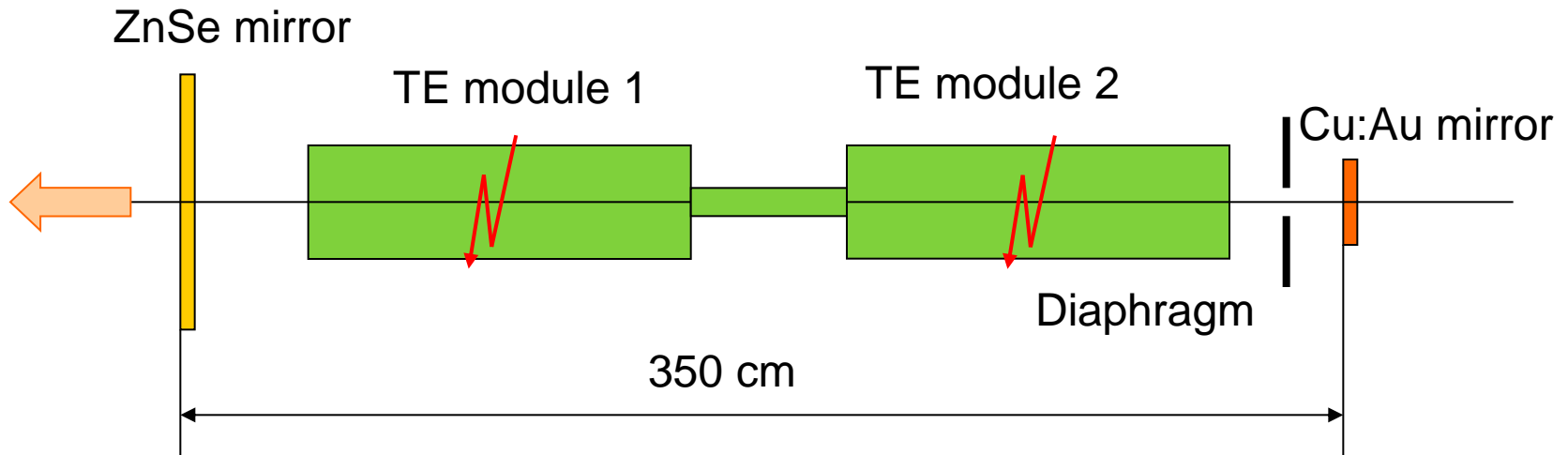


Tin droplets collected on glass witness samples  
at 73mm distance, 1k shot, 2.5J, 4μs



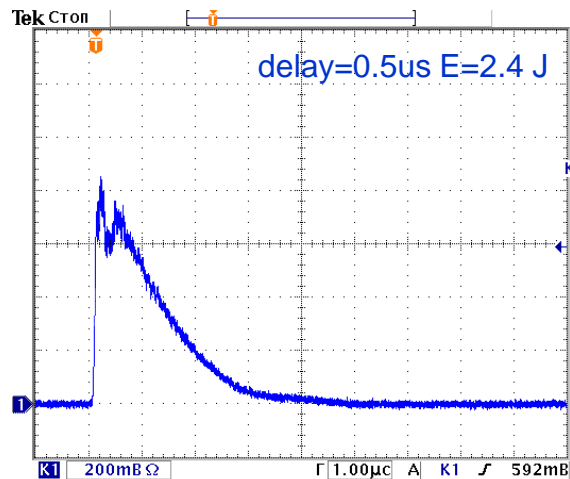
# Long pulse TEA CO<sub>2</sub> laser

## Laser cavity

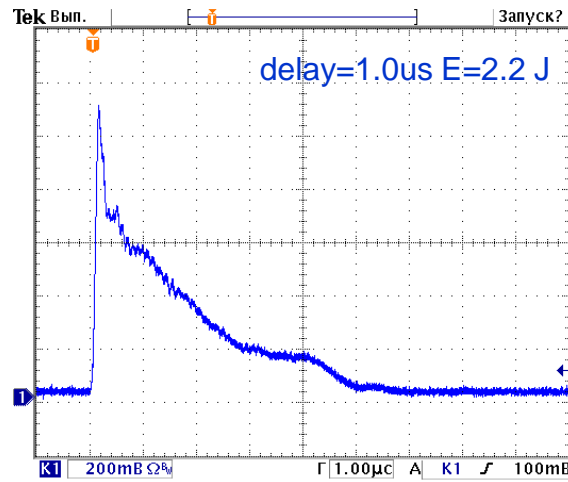


Variation of the gas mixture (CO<sub>2</sub>:N<sub>2</sub>:He) composition and the delay between modules produce different temporal shapes of laser pulse.

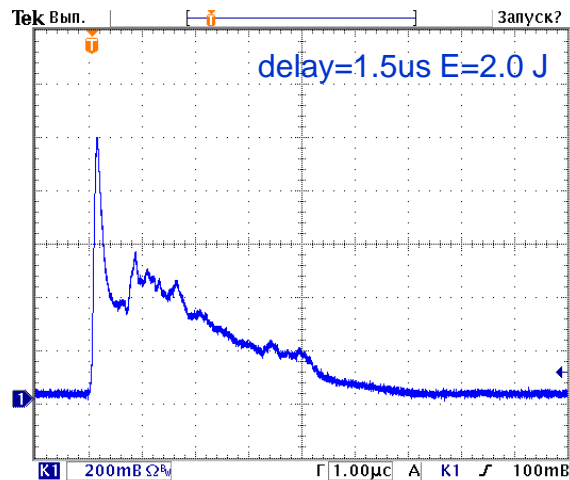
# Result of the delay variation



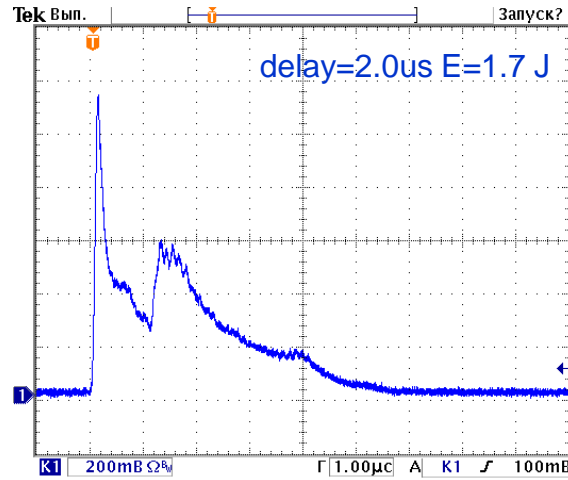
14 Фев 2013  
17:15:05



21 Мар 2013  
19:02:13



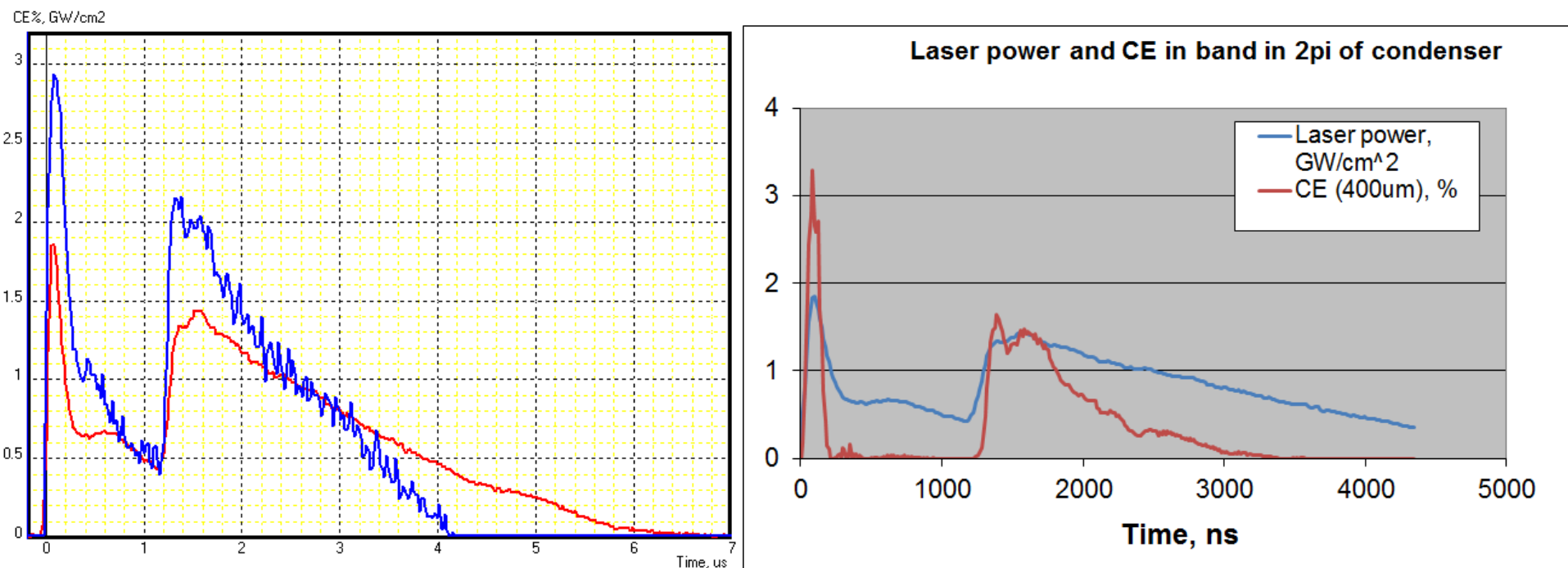
21 Мар 2013  
19:03:58



21 Мар 2013  
18:45:56

working mixture  $\text{CO}_2:\text{N}_2:\text{He}=1:4:11$

# Comparison of measured and calculated CE



Experiment:

Measured instant CE at 2.5 J

Laser spot  $\sim 400 \mu\text{m}$

Red – laser power (GW/cm<sup>2</sup>)

Blue – instant CE (% $, 2\pi$ )

RZLINE cod:

instant CE calculated with

experimental laser power

Laser spot =  $400 \mu\text{m}$



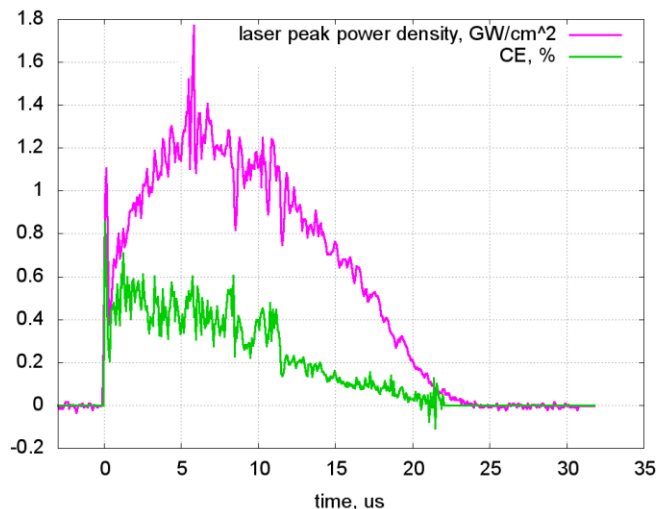
# Longer pulses are available with Electron Beam Sustained Discharge (EBSD) laser

## Parameters of EBSD laser in Lebedev's Institute (Moscow)

Lasing gas	CO <sub>2</sub>
Wavelength	10.6 $\mu\text{m}$
Pulse energy	10 – 80 J
Pulse duration	10 - 60 $\mu\text{s}$



Photo of mobile experimental setup  
for measurement parameters of LPP



Laser power density (red) and  
measured instant CE (green)

At long pulse mode reasonable value of  
CE – above 1 % requires to provide CO<sub>2</sub>  
laser power density not lower than 1 – 1.5  
GW/cm<sup>2</sup>

Required velocity of the Sn target is  
estimated as 100 m/s.

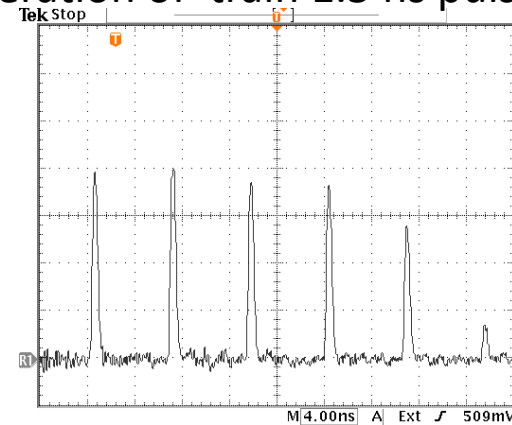
# Nd laser for LPP experiments



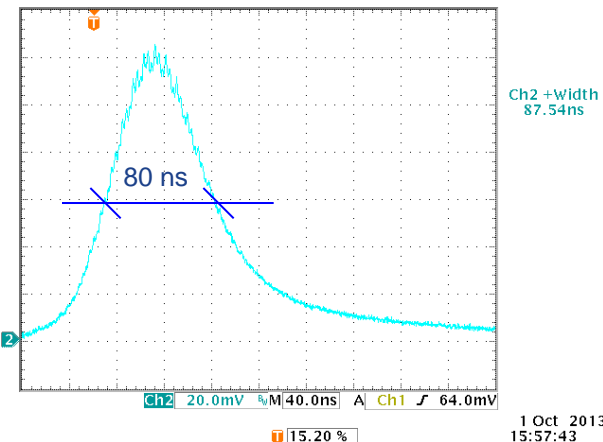
Wavelength: 1.06  $\mu\text{m}$   
Pulse energy: 0.15- 10J  
Duration: 1.5ns, 60 – 100 ns  
Beam quality:  $M^2 < 2$

## Possible modes of operation

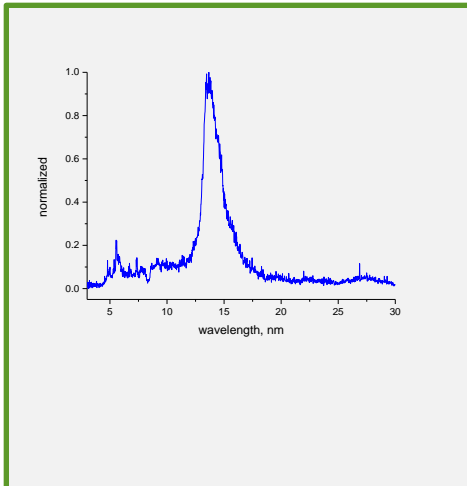
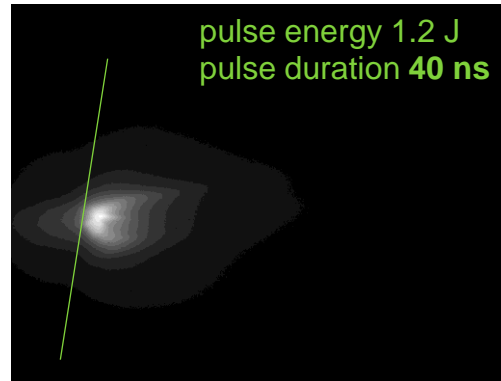
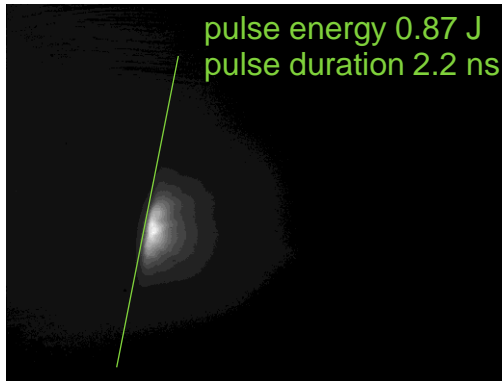
1. generation single pulse 1.5 ns, up to 600 mJ
2. generation of train 1.5 ns pulses



3. generation of long 60 – 100 ns pulse up to 10J



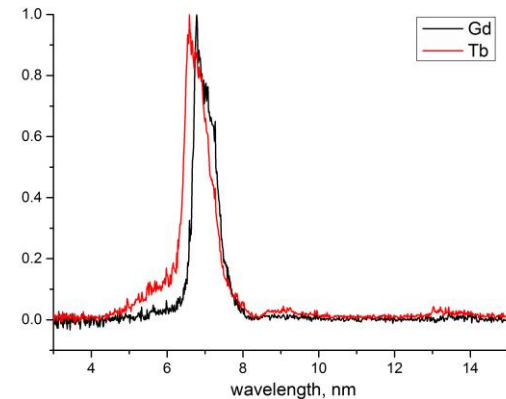
# Short pulse Nd – YAG Laser



Sn solid flat target  
Laser pulse 1.5 ns  
300 mJ, 30 – 50  $\mu\text{m}$   
focus spot;

High spectral purity  
High CE - 2 %

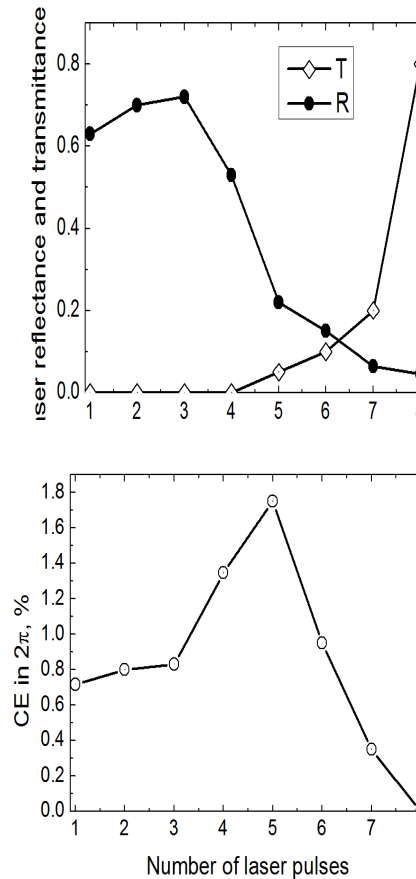
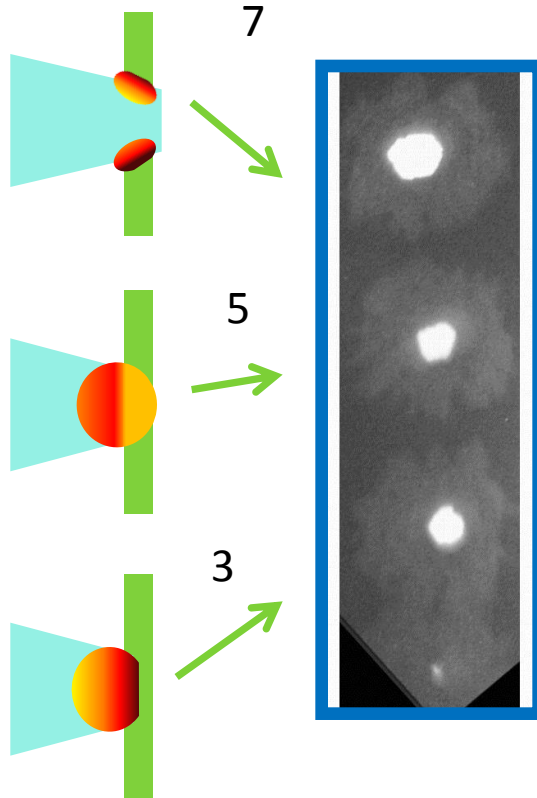
Spectra of Gd and Tb  
600mJ (Gd), 475mJ (Tb), 1.5ns, 30-  
50 $\mu\text{m}$  spot, double pulse



Usage of 1.5 ns laser pulse resulted in  
essential improve of “spectral purity”  
and higher CE = 1 % in 0.04 nm band.

# High CE with CO<sub>2</sub> laser in BEUV spectral range

CO<sub>2</sub> laser; target - Gd foil 80  $\mu\text{m}$

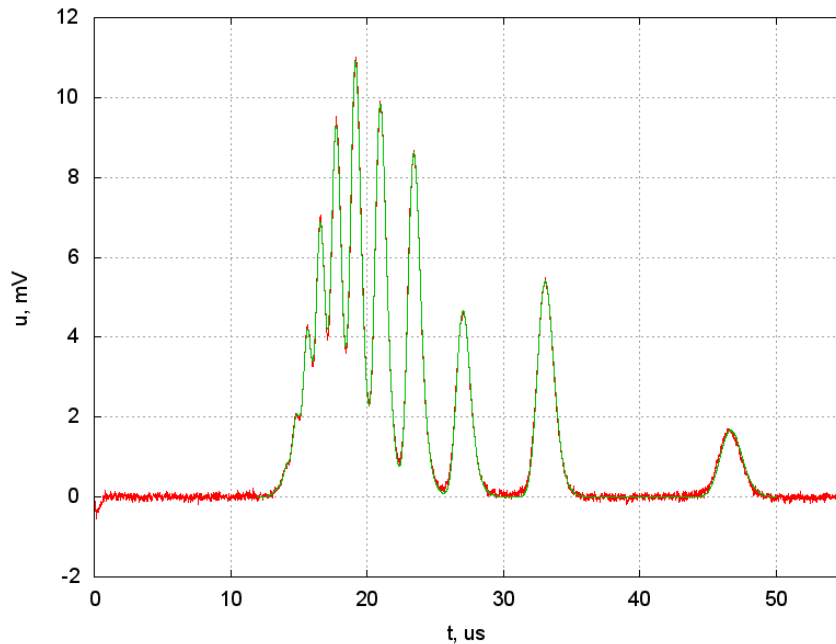


Perforation of the foil Gd target with repeated laser pulses allows to modify plasma expansion geometry:

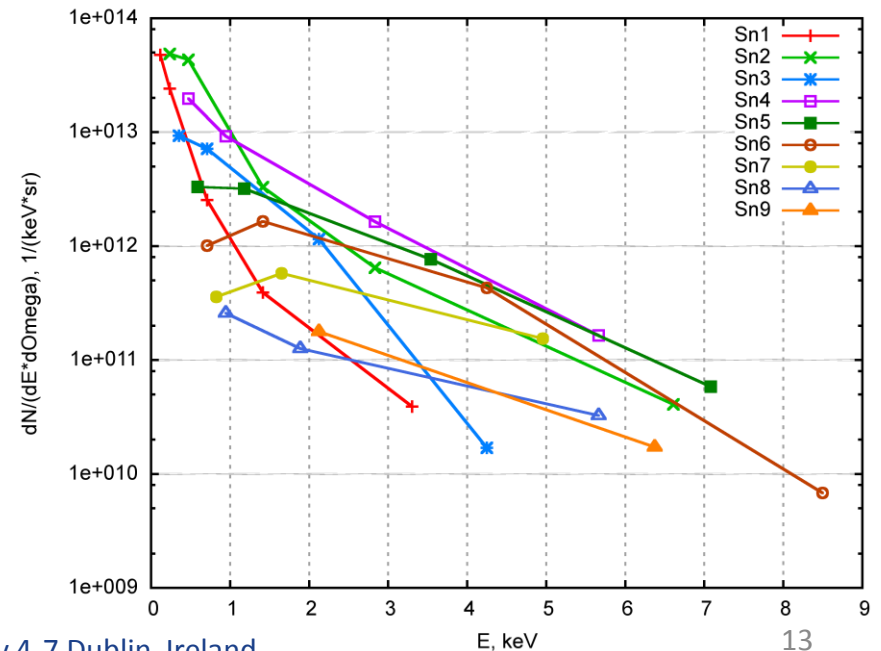
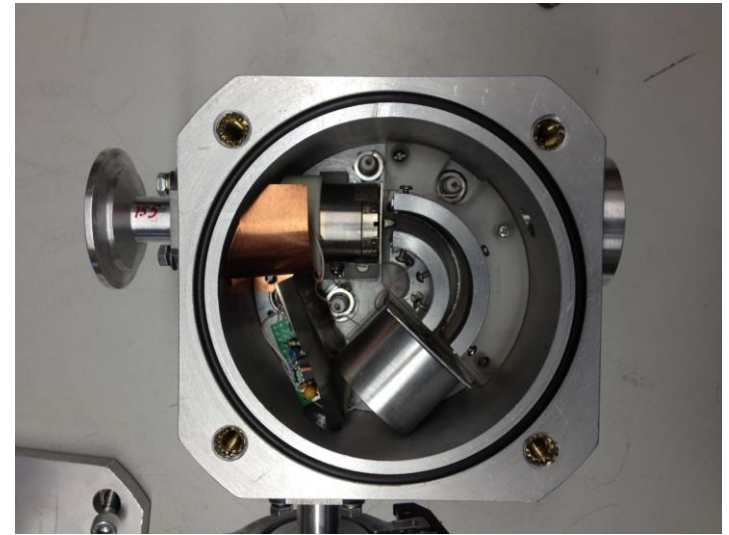
- Smooth plasma density gradient along laser axis results in the increase of laser light absorption
- Lower plasma density in laser plume results in low optical opacity for the useful 6.7 nm radiation

**• CE as high as 1,8 % in 0.04 nm band has been demonstrated**

# Characterization of ion debris from LPP plasmas



Fit of experimental records of ionic spectra fulfilled simultaneously in both – energy and time domains significantly improves quality of the ionic debris analysis.



# People contributed to the presentation

RnD-ISAN/ISAN: V. Medvedev  
V. Ivanov



ASML: V. Banine, A. Yakunin



## Thank You for Your Attention